

What is claimed is:

1. A plasma immersion ion implantation reactor for  
5 ion implanting a species into a surface layer of a  
workpiece, comprising:

an enclosure comprising a side wall and a ceiling  
and defining a chamber;

10 a workpiece support pedestal within the chamber  
having a workpiece support surface facing said ceiling and  
defining a process region extending generally across said  
wafer support pedestal and confined laterally by said side  
wall and axially between said workpiece support pedestal and  
said ceiling;

15 said enclosure having at least a first pair of  
openings at generally opposite sides of said process region;

20 a first hollow conduit outside of said chamber  
having first and second ends connected to respective ones of  
said first pair of openings, so as to provide a first  
reentrant path extending through said conduit and across  
said process region;

gas distribution apparatus on or near an interior  
surface of said reactor for introducing a process gas  
containing the species to be ion implanted;

25 a first RF plasma source power applicator for  
generating a plasma in said chamber.

2. The reactor of Claim 1 wherein said enclosure  
further comprises a base, and said interior surface of said  
30 reactor comprises one of: (a) said ceiling, (b) said side  
wall, (c) said conduit, (d) said base.

3. The reactor of Claim 1 further comprising a  
pumping annular volume defined between said workpiece  
35 support pedestal and said side wall, and a vacuum pump  
coupled to said pumping annular volume.

4. The reactor of Claim 1 wherein said first RF source power applicator is positioned to couple RF plasma source power into a region of said first hollow conduit.

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5. The reactor of Claim 1 wherein said plasma comprises a plasma current in said reentrant path that oscillates at an RF frequency of said first RF plasma source power applicator.

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6. The reactor of Claim 1 wherein said first hollow conduit comprises a metal material, said reactor further comprising:

an annular insulating gap in said first hollow conduit separating said first hollow conduit into axial sections.

7. The reactor of Claim 5 wherein said ceiling comprises a constriction of said reentrant torroidal path in said process zone for enhancement of plasma ion density of said plasma current in said process zone.

8. The reactor of Claim 5 wherein said ceiling and said wafer support pedestal are separated by a gap therebetween, said gap being sufficiently small so that plasma ion density of said plasma current is greater in the vicinity of said workpiece support pedestal than elsewhere along said reentrant path.

30 9. The reactor of Claim 1 wherein the workpiece support pedestal comprises an electrostatic chuck, said electrostatic chuck comprising thermal control apparatus for workpiece temperature control.

35 10. The reactor of Claim 9 further comprising a bias RF power generator coupled to said workpiece support

pedestal to control a sheath voltage across a plasma sheath overlying said workpiece support pedestal.

11. The reactor of Claim 9 further comprising a bias  
5 RF voltage generator coupled to said workpiece support pedestal to control a sheath voltage across a plasma sheath overlying said workpiece support pedestal.

12. The reactor of Claim 1 further comprising a gas  
10 supply containing said process gas.

13. The reactor of Claim 12 wherein said species to be implanted comprises a first atomic element, said process gas further comprising:

15 a second atomic element in chemical combination with said first atomic element.

14. The reactor of Claim 13 wherein said surface layer of said workpiece is a semiconductor material and said first 20 atomic element is an n-type or p-type conductivity dopant impurity with respect to said semiconductor material.

15. The reactor of Claim 14 wherein said second atomic element comprises a semiconductor element.

25 16. The reactor of Claim 15 wherein said second atomic element and said semiconductor material of said surface layer are the same atomic element.

30 17. The reactor of Claim 14 wherein said second atomic element is an element having a greater tendency than said first atomic element following ion implantation to diffuse out of said surface layer upon heating of said surface layer.

35 18. The reactor of Claim 14 wherein said second atomic

element comprises one of hydrogen and fluorine.

19. The reactor of Claim 14 wherein the chemical combination of said first and second atomic species 5 comprises a first molecular species, said process gas further comprising a second molecular species.

20. The reactor of Claim 19 wherein said second molecular species comprises one of: (a) hydrogen-containing 10 gas, (b) fluorine-containing gas.

21. The reactor of Claim 19 wherein said second molecular species comprises a diluent gas.

15 22. The reactor of Claim 21 wherein said first molecular species comprises a fluoride of said dopant impurity and said second molecular species comprises a hydride of said dopant impurity.

20 23. The reactor of Claim 22 wherein said process gas further comprises a third molecular species.

25 24. The reactor of Claim 23 wherein said third molecular species comprises a diluent gas.

25 25. The reactor of Claim 23 wherein said third molecular species comprises at least one of (a) hydrogen-containing gas, (b) fluorine-containing gas, (c) an inert gas.

30 26. The reactor of Claim 1 further comprising:  
a second pair of openings through said enclosure  
at generally opposite sides of said process region and  
displaced from said first pair of openings;  
35 a second hollow conduit outside of said chamber  
having first and second ends connected to respective ones of

1        said second pair of openings, so as to provide a second  
2        reentrant path through said conduit and across said process  
3        region transverse to said first reentrant path; and

4                a second plasma source power applicator coupled to  
5        said second hollow conduit for generating a plasma current  
6        in said second reentrant path.

7        27. The reactor of Claim 26 further comprising one or  
8        more RF power source for furnishing RF power to said first  
9        and second RF power applicators.

10        28. The reactor of Claim 27 wherein said RF power  
11        source furnishes RF power to said first and second RF power  
12        applicators at respective RF frequencies offset from one  
13        another.

14        29. The reactor of Claim 26 wherein said first and  
15        second paths are non-parallel and intersect one another in  
16        said process region.

17        20        30. The reactor of Claim 29 wherein said first and  
18        second paths are generally orthogonal to one another.

19        25        31. The reactor of Claim 1 wherein said gas  
20        distribution apparatus comprise a gas distribution plate on  
21        said ceiling.

22        30        32. The reactor of Claim 1 wherein said gas  
23        distribution apparatus comprises a gas distribution ring on  
24        said wall.

25        35        33. The reactor of Claim 1 wherein said enclosure  
26        further comprises a base, and said gas distribution  
27        apparatus comprises a plurality of discrete gas injection  
28        nozzles or diffusers on one of: (a) said side wall, (b) said

ceiling, (c) base of said chamber.

34. The reactor of Claim 26 wherein said first and second RF power applicators comprise respective conductors 5 coiled around respective ones of said first and second hollow conduits, said respective conductors being coupled to respective ones of said first and second RF power sources.

35. The reactor of Claim 26 wherein said ports are in 10 said ceiling, whereby said hollow conduits terminate axially into said ports.

36. The reactor of Claim 26 wherein said ports are in said side wall, whereby said hollow conduits terminate 15 radially into said ports.

37. The reactor of claim 26 wherein said ports are in said base of said chamber, whereby said hollow conduits terminate axially into said ports.

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38. The reactor of Claim 1 further comprising a bias power generator coupled to said workpiece support pedestal to control a sheath voltage across a plasma sheath overlying said workpiece support pedestal.

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39. The reactor of Claim 1 further comprising a bias voltage generator coupled to said workpiece support pedestal to control a sheath voltage across a plasma sheath overlying said workpiece support pedestal.

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40. The reactor of Claim 38 wherein said bias power generator has an RF bias frequency sufficiently low to enable ions traversing the plasma sheath to attain an energy corresponding to a peak-to-peak voltage of said bias power 35 generator.

41. The reactor of Claim 38 wherein said bias power generator has an RF frequency sufficiently high to limit RF voltage drops across dielectric layers on said workpiece support pedestal to less than a predetermined fraction of plasma sheath voltage near said workpiece support.

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42. The reactor of Claim 41 wherein said predetermined fraction corresponds to about 10%.

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43. The reactor of Claim 28 wherein said offset frequencies are centered around 10 MHz and are offset by about 200 kHz.

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44. The reactor of Claim 26 wherein said first and second hollow conduits are non-intersecting whereby said first and second paths intersect one another only in said process region.

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45. The reactor of Claim 1 wherein said gas distribution apparatus is in said ceiling and comprises a center orifice and plural outer orifices in a circle centered on said center orifice, said reactor further comprising:

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a gas panel containing a separate gas supplies for respective process gases for doping and for passivating and for removing; and

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a gas distribution controller comprising a first set of valves coupling at least one of said separate gas supplies to said center orifice and a second set of valves coupling at least some of said separate gas supplies to said plural outer orifices.

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46. The reactor of Claim 1 wherein said gas distribution apparatus comprises first and second sets of plural orifices, said reactor further comprising:

a gas panel containing a separate gas supplies for respective process gases for doping and for passivating and for removing; and

5 a gas distribution controller comprising a first set of valves coupling at least one of said separate gas supplies to said first set of plural orifices and a second set of valves coupling at least some of said separate gas supplies to said second set of plural orifices.

10 47. The reactor of Claim 45 wherein:

    said gases for doping comprise a fluoride of a dopant species and a hydride of a dopant species,

    said gases for passivating comprise a hydride of a passivating species and a fluoride of a passivating species,

15      said gases for removing comprise an etchant-containing gas and an inert gas; and

    said gases for oxidizing comprise oxygen.

48. The reactor of Claim 46 wherein:

20      said gases for doping comprise a fluoride of a dopant species and a hydride of a dopant species,

    said gases for passivating comprise a hydride of a passivating species and a fluoride of a passivating species,

25      said gases for removing comprise an etchant-containing gas and an inert gas; and

    said gases for oxidizing comprise oxygen.

49. The reactor of Claim 47 wherein said gas distribution controller furnishes oxygen exclusively to said 30 center orifice.

50. The reactor of Claim 48 wherein said gas distribution controller furnishes oxygen exclusively to said second set of plural orifices.

controller for controlling said bias power generator to produce a desired bias voltage at said workpiece support pedestal for a predetermined single burst duration.

5        52. The reactor of Claim 51 wherein said controller comprises:

      a timer for switching the output of said bias power generator on and off in accordance with said predetermined duration;

10        a peak voltage detector coupled to said workpiece support pedestal;

      a threshold comparator connected to said timer for comparing the output of said peak voltage detector with a predetermined threshold voltage;

15        a subtractor having a pair of inputs connected to the output of said peak voltage detector and to a predetermined target voltage, respectively, and a feedback conditioner for processing the output of said subtractor;

20        a first switch for coupling an output of said feedback conditioner to a power level control input of said bias power generator;

      53. The reactor of Claim 52 wherein said controller further comprises a control element for controlling said bias power generator (a) empirically in absence of a plasma in said chamber and (b) in a feedback control loop in the presence of plasma in said chamber.

      54. The reactor of Claim 53 wherein said control element comprises:

      a voltage-to-power look-up table having an input connected to said predetermined target voltage and an output;

35        a second switch coupled between the output of said voltage-to-power look-up table and said power level control input of said bias power generator; and

a plasma detector in said chamber connected to control said first and second switches in complementary fashion in response to detection of plasma in said chamber.

5 55. The reactor of Claim 54 wherein said plasma detector is further connected to enable said timer.

10 56. The reactor of Claim 52 wherein said feedback conditioner is an integral proportional controller.

57. The reactor of Claim 52 wherein said predetermined threshold voltage and said predetermined target voltage are identical.

15 58. The reactor of Claim 52 further comprising a process controller for furnishing said predetermined target voltage and said predetermined threshold voltage.

20 59. The reactor of Claim 1 further comprising a vacuum pump and a vacuum control valve coupling said vacuum pump to said chamber, said vacuum control valve comprising:

a valve housing having a valve opening defined by an opening side wall having a surface parallel to an axis of said valve opening;

25 a rotatable flap subject to process control and having an area conformal with said valve opening and side wall and rotatably mounted within said valve opening to define a gap therebetween; and

30 a plurality of small indentational voids in said side wall that are covered by said rotatable flap whenever said flap is in a co-planar relationship with said housing and are gradually exposed as said flap rotates away from said rotational position and before a bottom corner edge of said flap passes a top surface of said valve housing.

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60. The reactor of Claim 1 wherein said workpiece

support pedestal comprises:

    a conductive wafer support plate;

    a grounded conductive base plate forming at least a void between said support and base plates;

5       a side wall around said support and base plates forming at least a void between said side wall and said support and base plates;

    a high dielectric filler material having a high break-down voltage filling said voids; and

10       a conductive insert coupled to said bias power generator and a conductive female receptacle for tightly receiving said conductive insert, said conductive female receptacle being connected to said conductive wafer support plate, said conductive insert and said conductive female receptacle extending through said conductive base plate to said conductive wafer support plate, and insulating layer insulating said conductive insert from said conductive base plate.

20       61. The reactor of Claim 60 wherein said workpiece support pedestal further comprises at least one lift pin assembly extending through said conductive base plate and said conductive wafer support plate and a axial void between said lift pin assembly and said lift pin assembly, and a high dielectric filler material having a high breakdown voltage within the void between said lift pin assembly and said conductive wafer support plate.

30       62. The reactor of Claim 61 further comprising a fastening bolt extending at least partially through said conductive wafer support plate and to said conductive base plate, and a high dielectric filler material having a high breakdown voltage surrounding a portion of said bolt within said conductive wafer support plate.

source power generator coupled to said first RF power applicator and an RF bias power generator coupled to said workpiece support pedestal.

5        64. The apparatus of Claim 63 wherein said RF source power generator and said RF bias power generator comprise first and second pulsed RF supplies, respectively.

10        65. The apparatus of Claim 64 wherein said first and second pulsed RF supplies are in a push-pull relationship.

15        66. The apparatus of Claim 64 wherein said first and second pulsed RF supplies are in an in-synchronism relationship.

15        67. The apparatus of Claim 64 wherein said first and second RF supplies are in a symmetric relationship.

20        68. The apparatus of Claim 64 wherein said first and second RF supplies are in a non-symmetric relationship.

25        69. The apparatus of Claim 1 further comprising:  
              an RF source power generator connected to said first RF power applicator;  
              a D.C. bias power generator connected to said wafer support pedestal.

30        70. The apparatus of Claim 69 wherein:  
              said RF source power generator and said D.C. bias power generator supply comprise first and second pulsed power supplies.

35        71. The apparatus of Claim 70 wherein said first and second pulsed power supplies are in a push-pull relationship.

72. The apparatus of Claim 70 wherein said first and second pulsed power supplies are in an in-synchronism relationship.

5 73. The apparatus of Claim 70 wherein said first and second pulsed power supplies are in a symmetrical relationship.

10 74. The apparatus of Claim 70 wherein said first and second pulsed power supplies are in a non-symmetrical relationship.

15 75. The apparatus of Claim 38 wherein said bias power generator has a bias frequency that is sufficiently low for ions in a plasma sheath near said workpiece to follow electric field oscillations across said sheath at said bias frequency.

20 76. The apparatus of Claim 75 wherein said bias frequency is sufficiently high so that RF voltage drops across dielectric layers on said workpiece do not exceed a predetermined fraction of the RF bias voltage applied to said workpiece support.

25 77. The apparatus of Claim 76 wherein said predetermined fraction corresponds to about 10%.

78. The apparatus of Claim 38 wherein said bias power generator has a bias frequency between 10 kHz and 10 MHz.

30 79. The apparatus of Claim 38 wherein said bias power generator has a bias frequency between 50 kHz and 5 MHz.

80. The apparatus of Claim 38 wherein said bias power generator has a bias frequency between 100 kHz and 3 MHz.

81. The apparatus of Claim 38 wherein said bias power generator has a bias frequency of about 2 MHz to within about 5%.